To give some idea of the frequency of tropical hurricanes a table is attached giving dates of all that have occurred on the coast of South Carolina for two centuries.

Hurricanes on the coast of South Carolina.

Year.	Month.	Day.	Lives lost.	Moon's age.
1700	Sept	16		1
1713	...do	16		25
1728	...do	14		8
1752	...do	15	20	5
1787	...do		23	
1797	...do	5		12
1804	...do	7		1
1811	...do	10		22
1813	Aug	27	15	0
1815	Sept	28		25
1822	...do	27	200	10
1830	Aug	16		27
1837	Sept	1		0
1841	...do	16		29
1844	Oct			
1846	Aug	16		23
1850	...do	24		16
1851	...do	24		27
1852	...do	27		11
1854	Sept	7		14
1871	Aug	19		3
1874	Sept	28	2	16
1878	...do	11		13
1881	Aug	27		3
1882	Oct	11		29
1885	Aug	25	21	14
1893	...do	27	2,000	14
1893	Oct	13	25	2
1894	Sept	27		27

The above table gives the dates of all tropical hurricanes that have visited the coast of South Carolina during the last two centuries of which record can be found. Where loss of life on land is mentioned, the estimated number is given. The moon's age at each date is also shown, to indicate whether the hurricane occurred nearest the time of spring or neap tides. Of 29 in all, 16 fell nearest to the spring tides, and 11 the neap.

REPORT ON THE TORNADOES OF MAY 25 IN THE STATE OF MICHIGAN.

By NORMAN B. CONGER, Inspector, Weather Bureau (dated Detroit, June 22, 1896).

The data for this report is gathered from all reliable, available sources, but the most reliable data is contained in the report of the committee on cyclone damages appointed by Governor John T. Rich to ascertain the total damages and the amount of relief necessary in the district covered by the tornado. The report of this committee covers the counties of Oakland and Lapeer only, and it is in this district that the majority of the damage occurred, and where the tornado was most severe. That report covers the path of the storm so fully that it will not be necessary to repeat it. Reports were also received from the postmasters at Dryden, Utica, Amadore, Fostoria, Otisville, Oakwood, Ortonville, Otterlake, Metamora, Thomas, and one by Mr. Alexander G. Burns, of this office, who made personal inspection of the track of the storm that passed over Walkerville, Canada, just across the river from Detroit.

I made a personal visit the day after the storm to Thomas (Oakland County) to observe the action of the tornado and to follow its path for a short distance and observe its characteristics. The greatest damages were observed at Ortonville, Oakwood, and Thomas, in the northeast corner of the county.

I have made a careful study of the path of the storm at Thomas, Oakland County, and inclose a sketch, Chart No. VIII, drawn by Mr. E. F. Hulbert, showing the manner in which the storm distributed the debris.

The path of the storm was distinctly marked at Thomas. The south side of the storm showed all the trees, houses, and fences thrown to the northeast, while in the center of the path, which was probably an eighth of a mile in width at this point, the debris was laid to the east. The fence rails were laid due east and west, and all were laid out as carefully as though placed there by the hand of man. No two rails were laid one on another. On the north side, where the distinct path was of the same width as the center, the houses and debris were all turned to the south or southwest, with some few pieces lying to the west. From conversation with those who had visited the whole district, I learned that the same characteristics were observed throughout the length of the path. It was noticed in the center of the path that the grass was pounded down into the earth as though it had been washed into the earth by a heavy flow of water. The small trees on the south side of the path were stripped of their bark, even to the twigs, as though done by the careful hand of an experienced artisan. On one side of the road which runs north, at Thomas, the house of Mr. Kidder was carried bodily for about 300 feet, and then smashed into the earth, the contents of the house scattered beyond finding, while across the road, some 600 feet to the north, the frame house of Mr. Copland was taken free from the stone foundation, and the debris were found from 2 to 10 miles farther east-northeast. All that was left of his house was a square piano, which was standing on its side some 200 feet directly north of the foundations of the house, one end being pounded full of grass. One peculiarity of the freaks of this storm was the unroofing of the post office at Thomas, leaving only the lower story standing, and in the window was still displayed the weather forecast card of the day: "Severe local thunderstorms this afternoon and to-night; showers followed by fair, Tuesday." The forecast had been terribly fulfilled in this section.

Tornadoes occurred, or windstorms were reported, at about 6 p. m., local time, and at about 20 localities in the following counties, as represented on the map: Montcalm, Kalkaska, Midland, Bay, Tuscola, Genesee, Lapeer, Oakland, Macomb, St. Clair, Sanilac, and Wayne, the most damage occurring in the counties of Oakland, Lapeer, and Genesee, in the order named. That in Kalkaska County simply cut a path through the woods, and did not touch any houses.

The report of the damages from the storm at Mr. Clemens', Macomb County, has not been received, but the storm was quite severe there, and 2 lives were lost.

The reports from all sources indicate that there were 45 lives lost, about 100 persons injured more or less severely, and about $400,000 in damages to houses, barns, etc. The report of the committee gives also the amount of damage to crops, orchards, and fences in Lapeer and Oakland counties only.

KITE EXPERIMENTS AT THE WEATHER BUREAU.

By C. F. MARVIN, Professor of Meteorology, U. S. Weather Bureau.
[Continued from April REVIEW.]

IN the April REVIEW the manner of using steel wire for the kite line was described and the results of experiments given, showing the strength and the best arrangement of the wire, splices, string, and other members composing the kite line. The means employed for determining accurately the length of wire unwound from the reel in any case were also given. We will next consider the action of the forces on kites and the form and construction of those with which experiments were made at the Weather Bureau.

General remarks on single plane and cellular kites.—Before the writer began work upon the kite problem many efforts had been made to reach great elevations with kites of the Malay type, the construction of which has already been described. It was often found that these kites would not continue to behave properly hour after hour. When several kites were flying in tandem they would fly very nicely for a time, but a strong gust of wind or the continued action of moderate winds would cause some derangement in one or more of the kites. This would mar the success of the experiment, if it did not bring about some worse result. The real cause of such difficulties was not fully understood at that time. Subsequent experience with other forms of kites has shown how some of the difficulties might have been avoided. The general conclusion, however, is that single-plane kites are believed to be less reliable than kites of the cellular type. The latter are necessarily heavier in construction, but the several sustaining surfaces seem to be disposed in a manner to act with greater efficiency. The cellular or multi-plane kites are also far steadier than single-plane kites, and we believe that they are better adapted than the latter to maintain their equilibrium under great variations of wind force. On the other hand, the single-plane kites, on account of their lightness per unit area, are probably superior to the cellular kites in light winds. Single-plane kites generally prove to be steadier when the covering is fitted loosely, so that it bellies backward with the wind pressure. This looseness, however, is objectionable, for the reason that it is difficult to make the two halves of the kite perfectly symmetrical. The covering, which is generally of cloth, is likely to stretch unevenly with exposure to winds. The kite thereby becomes unsymmetrical, even while in the air, and begins to behave badly. Probably no greater source of difficulty with single-plane kites exists than the uneven stretching and flexure of the material of the kite. The symmetry of the kite is thus impaired. The ill effects of uneven stretching are greatly aggravated in kites in which the cloth is necessarily cut on the bias, as is noticeably the case in kites of the Malay type. Moreover, a nicer condition of symmetry is necessary in the less stable single-plane kites than in the more stable, steady, cellular forms. In these latter, too, the stretched surfaces of covering material are, as a rule, rectangular in form. Stretching, therefore, is apt to take place in a symmetrical manner and is then attended with little or no ill effect.

From such considerations as these, and the promising results of a few preliminary experiments with a Hargrave kite, the writer was led to adopt the cellular type of kite for further development. He still hopes to be able to determine numerically the efficiency of single-plane kites, as has already been done for the cellular kites, and thereby be better able to judge intelligently of the relative merits of the two forms. As yet, however, the necessary observational data have not been obtained.

ANALYSIS OF FORCES ACTING ON KITES.

Explanation of terms.—The terms *pull*, *lift*, and *drift* are frequently employed in connection with kites, and, as confusion has arisen in the minds of some concerning their use, a full explanation of their meaning appears to be required.

Pull.—The force which tends to tear asunder the kite string is regarded by the writer as the *pull* of the kite, or the *tension* of the string. I do not see that any better or more descriptive words are needed. In the case of a long, deeply sagging line it is plain that the absolute direction in which the pull operates is very different at different points along the line, but always tangent thereto. Moreover, the intensity of the force is also different. We may, nevertheless, with perfect consistency and without confusion, call this force pull or tension at any and every point. To be explicit in speaking of the pull, we need to specify also the point at which the tension is exerted, or the direction in which it acts. We may imagine the kite to be nearly in the zenith and pull the wire upward at a high angle. There is nothing in this circumstance to cause us to change the name of the force under consideration, as has been done by some. The force is just as much as ever the *pull of the kite*, or the *tension of the wire*, no matter at what angle it may act. Such expressions, therefore, as the pull *at the kite* or the tension of the wire *at the reel* seem to me to carry a definite meaning with them.

Lift.—The inherent idea conveyed by the word lift, when used to designate some force, is that of an effort which is opposed to the force of gravity. In other words, a lifting force is an effort which is directed vertically upward. The use of this word in connection with kites will, perhaps, be made clearer by the following illustration: Suppose the string from a flying kite be tied to a heavy stone. The pull of the kite being exerted in an upwardly inclined direction, the tendency will be to both *lift* the stone off the ground and also to drag it across the surface. That portion of the total pull which tends to raise the stone directly off the ground is the *lift* of the kite.

Drift.—The foregoing illustration serves also to bring out the meaning of the word *drift*, as applied to the kite. That portion of the total pull which tends to drag the stone horizontally across the surface of the ground is called the *drift* of the kite. It is that effect of the total pressure of the wind on the kite which tends to cause the kite to drift horizontally along with the wind. The kite must, however, be held in restraint against the force of the wind, otherwise the drift, as a force, does not exist; if the kite is not restrained, motion sets up and the drift regarded as a force is greatly changed in amount.

In the language of mechanics these words are perfectly defined by saying that *drift* is the horizontal and *lift* the vertical component of the *pull*.

The *lift* of a kite is important for the reason that it measures the amount of weight that the kite can sustain. Weights to be sustained are usually attached to the string. It is a matter of importance at which point along the kite line a given weight to be sustained is attached, for a little study will show that the lift and drift have different values at different points of the line. The more the line sags between any two points the greater will be the differences between the corresponding forces at those points. Fig. 27 represents a long deeply sagging kite line, and will serve to illustrate further the relations between the lift, drift, and pull. At the point A, for example, the *pull* is represented by the line A, B, tangent to the wire. By drawing horizontal and vertical lines through both A and B, the line $A\ L$ represents the *lift*, the line $A\ D$ the *drift*. Similarly, at a the lift and drift are represented by the lines $a\ l$ and $a\ d$. In this case the line $a\ b$ is made equal to $A\ B$, that is, the tensions at the two points are regarded as equal. This could not be true in an actual case, as the pull at a will always be less than at A, depending upon the weight of the portion of wire $a\ A$. Nevertheless, even though the pull is regarded as uniform in the diagram, the lift and drift are seen to be noticeably different. At O, where we have supposed the line to be horizontal the lift has vanished entirely and the drift is numerically equal to the pull. At the reel the lift is no longer a true lifting force; it even acts downward. In other words, the lift is negative. If at any point the kite line were exactly vertical, then the drift would entirely vanish and the lift would be numerically equal to the pull at that point. Such cases will rarely occur as regular working conditions in practical kite flying for scientific purposes. They are noticed here merely for the sake of illustration. They represent some of the conditions that may temporarily obtain where a long line is out and the wind falls off so much in force that the wire sags down quite to the ground.

The effect of hanging a weight upon the kite string is shown at W. The line $W\ P$ represents the magnitude and direction of the pull of the string, $W\ G$ represents the force of gravity. $W\ P'$ is the resultant of these two forces, and the direction the string takes below the point W must be identical with $W\ P'$. Moreover, the length of the line $W\ P'$ represents the tension in the string below W.

Resolution and combination of forces.—To proceed intelligently with the construction of kites a general knowledge of the action of the forces thereon is necessary. For our present purpose we will consider kites of the tailless variety only. The position a kite takes in the air will depend upon the resultant effect of five forces acting upon it and the string. So far as the kite itself is concerned we may, however, leave the string out of account and the two forces affecting it, and deal only with the forces acting at the kite. In this case there are three forces: (1) The pressure of the wind on the surfaces of the kite. (2) The action of gravity on the mass of kite.(3) The pull of the string at the kite.

When the kite flies steadily in a fixed position these three forces are in equilibrium. Whenever they are not in equilibrium some one of them preponderates in a certain sense, and the kite shifts its position to the right or left, or rises or falls in such a manner as tends to reestablish equilibrium. That is, a properly made kite will behave in this way. With a kite of improper form and badly arranged parts, no matter how much it darts and shifts about, it is impossible for the kite to move into and stay in a position where the forces just balance each other. The conditions may be such that changes of position do not tend to bring the kite into static equilibrium. The kite, in such cases, may spin around and around in a circle whose diameter is sometimes quite small, but often very great; or, the kite may swing back and forth far to the right and left without finding a position in which it can fly steadily. Such kites, generally, will not continue to fly very long. The oscillations, gyrations, and darting motions which for a time contribute to maintain flight may either gradually bring the kite down lower and lower, or some change in the forces of a marked or critical nature may suddenly end all flight with a precipitate dash to the earth.

Of the three forces in action, gravity alone is perfectly constant in amount and direction. The tension on the string is a force that exists only as the result of the action of the other forces. The wind pressure, then, is the only force which varies independently, and the great problem is to arrange the surfaces and bridle of the kite so that it can promptly, constantly, and easily accommodate itself to the innumerable and often very great and very sudden changes which we find to occur in the force and direction of the wind.

Wind pressure on plane surface.—The pressure of the wind upon the kite surfaces is a very complex force. We are able to understand its action best by resolving it into component parts and separately studying the effects of each.

In Fig. 28, $A\ B\ C\ D$ represents, in cross section, a flat rectangular plate exposed to the wind in an inclined position. The windward and leeward edges of the plate are supposed to be perpendicular to the paper and therefore at right angles to the wind, which is supposed to move in lines parallel tq the paper. The thickness of the plate has been purposely exaggerated in order to give prominence to the effect of the wind on the edges of the plate. In kites the edge surfaces are of relatively small extent, but their influence is large enough to be important and it is necessary, therefore, to notice the effect this has on the total pressure. Experiments have shown that the wind will glide over a smooth surface, such as we have supposed our plane to be, with great freedom. In other words, the skin friction is exceedingly slight. The action of the wind upon the surface is, therefore, in the nature of a normal pressure exerted at every point. For if we suppose the skin friction to be zero, then the pressure at each point due to the wind will be exerted exactly at right angles to the surface at that point. In the case of slightly roughened, fuzzy, surfaces, such as the cloth used in kites, it may not be strictly admissible to wholly neglect skin friction. In this case the air must be regarded as catching upon the roughnesses of the surface and exerting a slight push or force which urges the plane along in the direction in which the streams of air are flowing over its surface. Fig. 29 shows on a larger scale these forces of pressure and friction as they may be conceived to act on a single point, P, of the surface. $P'\ P$ represents the relatively large pressure acting directly at right angles to the surface; $F\ P$ represents the feeble force of friction acting parallel to the plane. From mechanics we learn that the combined effect of these two forces is the same as that of a single force represented by the line, $Q\ P$, which is the diagonal of a parallelogram formed on the lines $P\ P'$ and $P\ F$. The total pressure on the whole surface of $A\ B$ is simply the sum of all the elementary pressures like $Q\ P$. If we may neglect skin friction the pressure of the wind acts at right angles to the surface. If the skin friction is great enough to require consideration, then we must regard the wind pressure as acting at a less angle than 90° to the surface. It may be added here that the wind pressure experienced by a plane surface is due to the diminution of the pressure of the air on the back, or lee side, of the plate as well as to the direct impact of the wind on the forward side. For our present purposes we need not push the analysis so far as to separate these effects but will combine them into a resultant pressure on the front face of the plate.

In Fig. 28 the pressure of the wind at numerous points of the surface is represented by several small arrows. These are made longer toward the forward edge, in order to indicate a fact, brought out by experiments, namely, that the pressures are more intense over the forward portions of an inclined plate. This is readily understood when we notice that the front edge of the plate receives the full force of the wind which, after having its direction of motion completely changed and made parallel with the surface, glides easily over the after portion of the plate without exerting much pressure. In dealing with pressures of this character we generally desire to consider the total pressure over the whole surface. Such a pressure will be called the *total normal pressure*, or simply *normal pressure*. By way of excuse for what may seem to be a misuse of the word normal in this connection, we may add that although we have already learned that when we include the effects of skin friction the wind pressure can not be strictly normal, that is, at right angles to the inclined surface; yet the friction effect is generally so small that we may for the present include it in the total pressure and still designate the combined effects by the convenient term, normal pressure, without serious inconsistency.

Center of pressure.—It is not enough to know that the total normal pressure on a plane is practically at right angles to the surface; we must also know the magnitude of the force and the point at which it acts. The point of application of the pressure is called the *center of pressure*, that is, the point at which, if all the forces be concentrated, their action produces the same effect as when the forces are distributed and act at every point of the surface. If the intensity of the pressure were the same at all points of the plate, then the center of pressure would be at the center of the surface. It was shown above, however, that with inclined surfaces the forces are most intense near the forward edges, therefore the center of pressure can not be at the center of the surface in such cases.

Many experiments have been made to determine both the magnitude and the point of application of the normal pressure on inclined surfaces of various kinds and for different wind velocities. Exact experiments are difficult to make, however, and the results obtained from various sources are more or less discordant with each other. In regard to the position of the center of pressure it is plain that if the forces are most intense toward the forward edge of the plate, as indicated in Fig. 28, then the center of pressure will be more or less forward of the middle point of the line, $A\ B$. (We have supposed the form of the plate represented by the line, $A\ B$, to be rectangular, with the front and after edges presented at right angles to the wind current.) Both the form of the plate and the manner in which it is presented to the wind will have much to do with the location of the center of pressure. Without, therefore, attempting to indicate correctly the location of the center of pressure on the supposed rectangular plate, we may represent the total normal pressure of the wind on the plate by some such line as $N\ O$. The angle, $A\ O\ N$, will be a trifle less than 90°, if we include the effects of skin friction. The center of pressure will be on the middle line between the right and left edges of the plate. It can not be otherwise, for there is no reason why the pressure of a uniform wind should be permanently unequal on the right and left halves of the plate.

Edge pressures.—The pressure on the forward edge of the plate may be represented by the line, $E\ P$, in the same way that $N\ O$ has been found to represent the pressure on the under surface, $A\ B$. To ascertain clearly the total effect of the wind on the whole plate we must combine the forces, $N\ O$ and $E\ P$. This is effected, according to the principles of mechanics, by prolonging the direction lines of the forces until they intersect and then constructing the parallelogram, $P'\ O'\ Q\ N'$. $N'\ O'$ is made equal to $N\ O$, and $P'\ O'$ is equal to $E\ P$. The diagonal line, $Q\ O'$, now represents the total effect of all the wind forces acting upon the plate, that is, the wind will tend to push the plate in the direction $O'\ Q$, with a force which is represented by the length of the line, $O'\ Q$. To hold the plate in equilibrium against the action of the wind it should be sufficient to introduce another force equal to $O'\ Q$ and opposed thereto, as the force $O'\ Q'$, for example.

Fig. 30 represents the action of the wind on the edge of a piece of cloth thickened by the cord in the hem to strengthen the material. The pressure of the wind on the rounded edge will tend to push the edge in the direction $A\ P$. The combination of this force, with the normal pressure represented by $N\ O$ (only a part of the surface is shown) may be effected by means of the parallelogram of forces $O'\ N'\ Q\ P'$. Here, again, the line $O'\ Q$ represents in magnitude and direction, the total effect of the wind on the surface in question.

In Fig. 30 the normal and the edge pressures are combined at the point O', obtained by the intersection of the lines $N\ O$ and $E\ P$ prolonged. This method is adopted in order to simplify the diagram. We are not to infer that the resultant pressure necessarily acts through the point O'. The edge pressure, $E\ P$ exists primarily as a tension in the cord in the hem of the cloth, and as such is communicated to the sticks of the kite. The precise manner of combining the forces in order to locate correctly the point of action, O', of the resultant will require special attention according to the conditions of a particular case, and need not be now considered.

Resultant pressure.—We have already designated the pressure represented by the line $N\ O$ as the total normal pressure. We will now adopt the expression *total resultant pressure*, or simply *resultant pressure*, as the name of the combined effect represented by the lines $O'\ Q$ in Figs. 28 and 30.

The important point it is designed to bring out in the foregoing treatment of the several pressures upon a plate is to show: (1) that the general pressure over smooth and extended plane surfaces may be regarded as practically normal to the surface, and (2) that the total resultant pressure on all surfaces (including the edges, sticks, struts, and other members, necessarily parts of the kite structure) is always inclined more or less away from a normal, as indicated by the lines $O'\ Q$, in the figures.

Thus far we have virtually supposed the plate to be perfectly flat, but kite surfaces, especially when made of paper or cloth, will rarely or never be quite flat, and the effects of curvature must, therefore, also receive our consideration.

Pressure on thin, curved surfaces.—The kind of curved surface commonly met with in kite work is simply the arched or bellied-out surface which results from the pressure of the wind on the more or less loosely-fitted cloth or paper coverings. This looseness is oftentimes intentional, for the reason that experiments show that the total pressure on inclined arched surfaces is greater than on the same extent of flat surface. In Fig. 31, let $A\ B$ represent a section of an arched surface, such as might exist in a kite. The curved line, $A\ B$, may be regarded as the path followed by a particle of air as it flows across the surface from the front to the rear edge. Here, again, so little is certainly known of the exact nature of the pressure of wind on such a surface that we cannot indicate its character correctly nor locate definitely the position of the center of pressure. In the case of a plane surface we found that the total pressure acted sensibly normal to the surface. In the case of arched surfaces we do not know certainly in just what direction the total pressure acts. Lilienthal, who has done so much to advance the art of flight with wings, has made a great many experiments from which he has deduced both the magnitude and direction of the pressure on arched surfaces.[1] His methods of experiment, however, and the results, especially in respect to the direction of the force, are affected by an error pointed out by A. v. Obermayer.[2] While it will scarcely be possible in a given case to predict what direction or at what point the total pressure is acting, yet we may state approximately that the center of pressure, generally, is forward of the middle of the arch, and the direction of action is at an angle of more than 90° to the chord of the arc. The line, $N\ O$, may be regarded as indicating the resultant normal pressure. The angle, $A\ C\ N$ will generally be greater than a right angle. As in dealing with pressures on plane surfaces we may still consistently designate the total pressure on arched surfaces as the normal pressure, for the reason that it may be conceived to be the sum total of the forces acting normally at every point of the arched surface. The curvature which Lilienthal finds from his experiments to be the most effective is that which makes the height of the arch about one-twelfth of the chord.

The foregoing analysis of the wind pressures on surfaces has been carried out in considerable detail because these matters are of fundamental importance in arriving at a clear understanding of the action of the kite. One can not ignore them and at the same time proceed intelligently to improve and perfect kites.

Effect of waviness, or fluttering.—It often happens, especially with some forms of kites, that the cloth fails to remain taut and smooth, but forms a series of waves flowing in the direction in which the wind moves over the surface. A section across a surface of this character will have some such appearance as shown in Fig. 32. The action is oftentimes very pronounced, and the kite emits a comparatively loud sound, due to the rapid fluttering of the cloth. The effect of this is a matter of serious consequence. The wind presses strongly upon the windward sides of the waves, and thereby tends to push the surface along in the direction $A\ B$. Supposing the surface free of waves, the resultant pressure might be represented by such a line as $O\ Q$. If, however, the wavy condition prevails, the resultant pressure will take such a direction as $O\ Q'$.

Whirls, or eddy effects.—There is another respect in which the action of the wind on the kite may be objectionable in character, that is, may tend to depress the kite or drag it onward with the wind. In the absence of a better name this may be called the whirl or eddy effect. In some forms of kites a greater or less portion of the whole current of air affected by the presence of the kite is broken up into

[1] Der Vogelflug als Grundlage der Flugekunst. Otto Lilienthal. Berlin. 1889.

[2] Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften. Vienna. October, 1895.

numerous whirls and eddies. These may be formed when the air flowing against the kite is suddenly stopped, or when its movement is abruptly changed and diverted to a new direction. Angles and changes in the continuity of the surfaces such as formed by the presence of the cross stick in the Malay kite, for example, and other causes that prevent the air from flowing easily and by smooth changes of motion over and past the kite, will give rise to eddies. Whirls of marked character exist over the leeward surfaces of the kite. Strong eddies may thus be set up at numerous points adjacent to the body or surfaces of the kite. It is possible, and indeed quite probable, that some of these may remain nearly stationary in certain favorable spots. Such eddies or whirls, in a certain sense, may have much the same effect as obstructions to the flow of the air. Quite as much of an obstruction may be thus formed as if an excrescence of rigid material were placed on the kite at one of the points in question. In cellular kites generally the cells are virtually short tubes through which large streams of air must flow. Pronounced eddy formations within these tubes have much the same effect as real obstructions by which the flow of the air is as it were choked up.

We can not attempt here to analyze in detail the action of these eddies. The illustrations employed above to aid the mind in forming a conception of some of their effects are known to be faulty and imperfect and open to the criticisms of the exact physicist. Nevertheless, we perceive, by the aid of the comprehensive principle of the conservation of energy, that the power required to form these eddies and maintain the air within them in rapid motion must be derived by reaction from the kite and its string. The necessary reaction can be derived from the kite only when its angular elevation is depressed in consequence.

It, therefore, results that when eddy effects are present with a given form of kite, any modification that will eliminate or lessen the eddies will enable the same kite to obtain a higher elevation, other things remaining the same.

We have already said that the equilibrium of any form of kite depends upon the action of three forces, one of which is the wind pressure. In the foregoing discussion we have aimed to show the complex nature of the force that we call the wind pressure. We will next endeavor to show the conditions which exist when equilibrium is established between the forces in question. It is well known by experience that a condition of equilibrium is possible between the forces which act on a well built Malay kite, therefore we will first select this form of kite as the subject of our analysis. As seen from the front, the kite appears as shown in Fig. 33. The surface is far from being flat. The line $A\,B$ is straight, but $C\,D$ is bowed forward, as indicated by the curved dotted line, $C\,D$, Fig. 34. Owing to its looseness the cloth is bellied backward by the wind pressure so that in a cross section on a line such as $c\,d$ the kite appears as shown in Fig. 34. Similarly a section on a line such as $a\,b$ appears as shown in Fig. 35.

The kite is held in restraint by means of the bridle which is attached only to the midrib of the kite. In certain respects, therefore, we may regard the midrib as a fixed axis about which the kite may tilt laterally more or less. We will first consider the equilibrium of the forces on the lateral halves of the kite.

Lateral stability.—In the case of loosely fitted coverings, the arching back of the surfaces in the manner indicated in the drawing is very pronounced, and tends to increase the stability of the kite against tilting edgewise to the wind.

The two halves of the kite either side of the midrib, $A\,B$, must be made very carefully, equal and similar in all respects. When so made, the pressures, acting as indicated in Fig. 34, will just balance each other in a uniform wind, and the kite will then poise on what we may call an even keel. When, however, from variations of the wind, the pressure on one side becomes greater than that on the other the kite is tilted over to some extent. The wing which momentarily received the greater pressure is moved laterally into a position of less inclination to the wind, and the intensity of the pressure is thereby diminished; whereas, the opposite wing being placed by the tilting in a position of greater inclination to the wind receives a corresponding increase of pressure and a balance between the opposing forces on the two wings is still preserved. If the covering of the kite is taut, so as to remain flat, the cross-section on $c\,d$ will appear more nearly as shown in Fig. 36. A kite with such a surface is also able to preserve a condition of equilibrium between the pressures on the two wings, for the surfaces by tilting more or less assume different degrees of inclination to the wind, and within reasonable limits a condition in which the forces are balanced is possible at all times. The bending backward of the lateral wing surfaces so as to form a dihedral angle, as shown in Fig. 36, lessens slightly the angle of inclination of the surfaces to the wind. The lifting effect in such a case is, therefore, less than with the same surface not so inclined, for it is plain that if the two wings were bent backward to such an extent as to meet each other, all the lifting effect would be gone. The slight loss in lifting power which occurs for the reason here given is, as it were, the price we must pay for the stability imparted to kites of this type. The amount of bending backward ought to be no greater than is required to contribute a sufficient safe-working stability.

If, however, the cross stick of the kite is not bowed or inclined backward in any manner and the covering is taut, the whole surface of the kite will be sensibly flat. Made in this way, the kite will be found to have lost all its lateral stability. Tilting sidewise does not, as formerly, restore the balance of forces, for, with a flat surface, a change of inclination affects the pressure on the whole surface in the same way, and there is no tendency for the tilting to produce a balance between unequal forces on the two halves of the plane. A perfectly flat kite of a single surface can not, therefore, be made to fly of itself. Tails will be required and other artifices must be adopted to keep it poised in the wind in a flying attitude. Even approximately flat surfaces, however, rarely or never exist in kites as ordinarily made. The wind pressures bend the sticks and belly out the covering in nearly all cases to such an extent and in such a manner that at least a slight condition of automatic stability is imparted to the kite.

We have explained in the foregoing how the forces on the lateral halves of the Malay kite surface automatically balance each other, even when the wind pressures are not uniformly distributed. We will next consider the equilibrium of the forces in a longitudinal sense, or in the fore and aft dimension of the kite.

Longitudinal stability.—We have already mentioned that the kite is restrained by means of the bridle attached only to the midrib. We need to now consider how the pressures of the wind upon the cloth surfaces are communicated to the members of the structure and finally to the midrib itself. The fibres of the cloth can resist the pressure of the wind only by virtue of tensional strains. Referring again to Fig. 34, the arched surfaces of the cloth there shown are under considerable tension, which, at the midrib, E, is exerted in the directions of the tangents $E\,T$ and $E\,T'$. There are similar tensional forces at C and D, which act upon the cord forming the perimeter of the kite. These strains are communicated in turn to the extremities of the two sticks, thus reaching the midrib directly or by means of the cross stick. The effect of the two forces, $E\,T$ and $E\,T$, is equivalent to a single force, $E\,P$. By a similar treatment of the reactions at the several portions of the kite frame, it will be found that all the forces may be concentrated upon the midrib. Let $A\,B$, Fig. 37, represent a side view of the midrib with the bridle attached. From what has preceded, it will be easily understood that the magnitude and direction of the total resultant pressure of the wind upon the kite may be represented by such a line as $Q\ O$. The center of gravity of the kite may always be found by well-known methods. Let g be the position of the center of gravity, then we may represent the weight of the kite by the line $g\ w$. The combined effect of both gravity and the wind is now found by means of the parallelogram of forces, $O'\ Q'\ R\ G$. The force represented by the line $O'\ R$ is the resultant effect of both the wind and gravity on the kite. The kite can be in equilibrium only when the string pulls in line with the force $O'\ R$ and through the point O'. The string from the bridle must, therefore, take the position and direction shown, viz, $O'\ F\ L$, and the tension on the string must be numerically equal to the force $O'\ R$.

Diagram of forces.—Fig. 37 is a typical diagram of the action of the forces on any kite. Such a diagram, especially that part including the parallelogram, $O'\ Q'\ R\ G$, and the string, $L\ F$, will hereafter be designated as a diagram of forces. We have mentioned before that the force of the wind is the only force that varies independently; that is, the line $O\ Q$ in the diagram requires to be made not only of different lengths, to represent, from moment to moment, the changing intensity of the wind force, but both the direction of the line, in relation to $A\ B$, and the position of the point O, are also constantly changing in correspondence with changes in the direction of the wind in reference to the kite. These changes of direction are partly real changes in the wind, but are also due to changes in the angle of incidence of the kite. The angle a in the diagram may, for present purposes, be regarded as the angle of incidence.

To follow a little further the action of the forces on the kite, let us suppose the wind pressure to increase in intensity without change of direction or point of application. Let the increased pressure be represented by the line $O'\ Q''$. The new resultant of the forces of wind and gravity will be the line $O'\ R'$. The pull of the string acting through the point O' is now no longer able to just oppose and balance the new resultant $O'\ R'$. These two are inclined to each other at a slight angle, instead of being exactly opposite in direction. Resorting again to the well known method of the parallelogram of forces for combining the now unbalanced forces on the kite, we find that there exists a small unbalanced effect, such as indicated by $O'\ M$, which urges the kite forward and upward in the wind. (To avoid confusion, the lines of the parallelogram are omitted from the drawing.) The movement which results from the action of the force $O'\ M$ causes several changes of conditions, thus, the angle of incidence changes, the direction of the string is made steeper; the point of application of the resultant wind pressure shifts and the force also changes in direction. By means of these changes new conditions are established in which complete equilibrium of the forces again results.

We may now see the reason for using the bridle $E\ F\ B$. If the string were tied directly to the kite at F', for example, the kite could be in equilibrium only when the *resultant* of the wind pressure and gravity passed through that point. Tied to the point F the point of intersection of the string with the kite can automatically shift and thus accommodate itself to numerous conditions. Moreover, the tension of the string acting at F and the wind pressing at O constitute a system of forces that are in stable equilibrium.

This advantage of arranging the string to draw from a point at a distance in front of the kite suggests that it be employed likewise to increase the lateral stability of the kite. For example, if $E\ F$, Fig. 38, represents the bridle as it is seen in the end view of the kite, the point F may be made fixed in reference to the kite by use of two steady lines attached to points on the cross stick, as at $f\ f$. Such, or an equivalent arrangement, that produces a fixed point in front of the kite from which the string may draw, will be of special advantage in the case of single plane kites whose surfaces are very nearly flat.

For the sake of simplicity it has been assumed in all that precedes concerning the diagram of forces, that the angle of inclination of the total resultant wind force, $Q\ O$, to the line, $A\ B$, can not be as great as 90°, which, for flat surfaces, represents an ideal condition of absolutely no edge resistance, skin friction, etc. This, however, may not necessarily be the case with arched surfaces, for we have already had occasion to point out, as shown in Lilienthal's experiments, that the total resultant pressure on certain thin arched surfaces may be inclined *forward* of the normal to the chord of the arch. Nevertheless, when ill effects such as those illustrated in Fig. 39 exist, the slight possible advantage gained by the effects of arched surfaces is more than offset by the defects that have been pointed out. Our assumption that the angle, $Q\ O\ B$, is less than 90° for both flat and arched cloth surfaces as ordinarily found, can not, therefore, be much in error. Furthermore, there is positive evidence from the experience of every flyer of the Malay kites that the angle of the total resultant force, $R\ F'\ B$, can not be as great as 90°. For, the angle, $B\ E\ F$, of the bridle is generally made at least 90°, and if $R\ F'\ B$ ever becomes as great as 90° it would mean that the lines $F\ L$ and $E\ F$ would coincide. A very slight acquaintance with kite behavior will convince one that this does not occur in practice. The direction of the string at $F\ L$ always falls between the strings $E\ F$ and $B\ F$.

Up to the present point we have proceeded to draw the diagram of forces as if the force, $O\ Q$, were fully known in magnitude, direction, and point of application. In practice this is just what we do not know. It is plain, however, that we may measure both the direction and the pull of the string at $F\ L$, and also determine its point of intersection with the kite. Furthermore, the weight and the position of the center of gravity of the kite are always determinable. Knowing, therefore, the resultant and one force for any given case, we are able to work the parallelogram of forces backward, as it were, and thus arrive at a complete knowledge of the unknown force, $O\ Q$.

Conditions that modify the angular elevation of the kite.—The direction of the string, $F\ L$, that is the inclination of the top end the kite string to the plane of the horrizon, considered in connection with the angle of incidence of the kite, is a fundamental datum in the analysis and comparison of the behavior of kites. When the string, from the ground to the kite is short and sensibly straight it will be noticed that the direction of the string at $F\ L$ measures the angular elevation of the kite from the reel. Any arrangement or modification which can make this line steeper, other conditions remaining the same, will be an improvement, for it means that the kite will tend to fly that much nearer the zenith. Bridling the kite so that the angle of incidence a is smaller will, in general, cause it to fly more nearly overhead, but we do not wish to consider this case now for the reason that lessening the angle of incidence lessens the pull of the kite at the same time. It is designed to consider here only those modifications that will increase the steepness of the line $F\ L$ without any change of the angle of incidence. We will reserve, for future consideration, the question as to what angle of incidence is best.

Let us observe the effects of the weight of the kite itself. In the parallelogram of forces, Fig. 37, the line $O'\ G$ represents the total weight of the kite. If the weight of the kite can be diminished then the line $O'\ G$ will be shorter in relation to $O'\ Q'$, and a new resultant, $O'\ r$, will be formed having a steeper angle than the resultant $O'\ R$. As the kite string in the new condition must come into line with $O'\ r$ we see that lessening the weight will cause the kite, other things remaining the same, to stand at a higher angular elevation. It will be noticed, also, that the resultant $O' r$ is longer than $O' R$; that is, the pull of the kite is greater.

There is another respect in which something may be done to increase the angular elevation of the kite. The line $O\ Q$ representing the total resultant wind pressure on the kite is not at right angles to $A\ B$. The angle $Q\ O\ B$ is less than 90°. As has already been explained the influence which deflects the line away from the normal is the pressure of the wind on the edge surfaces of the kite. It may appear that a kite of the Malay type presents a very small extent of edge surfaces upon which the wind can act. However, such is often only seemingly the case. By referring to Fig. 39, which shows a sectional view of the kite on such a line as $a\ b$, Fig. 33, we notice that owing to the arching upward of the cloth in front of the cross stick $C\ D$, the greater part of the surface $A\ C\ D$, Fig. 33, is presented to the wind at a much greater angle of incidence than the rest of the surface. In a certain sense this triangular front of the Malay kite as it narrows out to the points C and D is little else than an edge surface, and the wind pressure thereon is of the same harmful character as upon real edge surfaces. The normal pressure on this surface takes such a direction as $O\ N$, Fig. 39, and when this force is combined with the other pressures that act more nearly at right angles to the kite surfaces, the total resultant is inclined away from the normal more than would be the case in the absence of these harmful pressures. Returning now to Fig. 37 we notice that any influence which causes the line $Q\ O$ to incline backward and away from the normal to the line $A\ B$ will have the effect of giving a smaller angular elevation to the line $F\ L$, when equilibrium of the forces exists.

The above study of the diagram of forces has thus far led to two noteworthy conclusions, namely: (1) that changes in the weight of the kite have a direct effect on the pull of the kite and cause the angle of intersection of the string with the kite surfaces to change, thereby changing the angular elevation of the kite; (2) that the blowing backward and upward of the loose cloth in front of the cross stick $C\ D$ in kites of the Malay type has a very prejudicial effect upon the angular elevation of the kite. We may mention with these the following conditions which also tend to lessen the angular elevation of the kite, namely: (3) all pressures upon the edges of the kite; (4) the surfaces of the kite may flutter and take on a wavy character under the action of the wind. Attention was called to this ill-effect in a previous paragraph; (5) eddy effects.

Considerable attention has been given to the effects of edge pressure, whirls, waviness, etc., all of which cause the total resultant wind pressures on surfaces to take an inclined, rather than a normal, direction to the surface. In developing the kite so as to reach great elevations, any influence which tends to deflect the resultant wind pressure away from the normal to the kite surfaces tends to depress the kite away from the zenith by the same angular amount, and one most important point, therefore, in which to improve the kite is to diminish and eliminate, as far as possible, the edge pressures and all similar effects.

It is plain, therefore, as a result of the foregoing development of the ill-effects due to certain features of kite construction, that the expert designer must aim not only to make his kites as light as possible, but all waviness and fluttering must be suppressed, and all those influences which tend to deflect the direction of the total resultant pressure away from the normal be eliminated and diminished as far as possible.

We are now brought to the statement of a very important principle, the significance of which will more fully appear as the study of the action of the forces upon the kite is carried further. The principle has to do solely with the *direction*, relative to the kite, in which the wind pressure acts upon it. The *magnitude* of this force is a matter for separate consideration. The principle may be stated as follows: *The condition of ideal efficiency (that is, an efficiency of 100 per cent), in the action of wind forces upon a thin plane surface, obtains when the total resultant pressure is exactly normal to the surface.* The line $Q\ O'$, Fig. 28, will, in the ideal case, form a right angle with $C\ D$ and be in the plane of the paper. With material plane surfaces the angle $Q\ O'\ P'$ will generally be less, it can not be equal to or greater than a right angle. We have seen that with an arched surface the resultant may make an angle greater than 90° with the chord of the arc, but we are unable for the present to extend the above principle to the case of arched surfaces, as thus far no sufficiently exact knowledge of the direction of the resultant pressure exists to justify a statement of its limiting direction in the ideal case. In the development of the kite for the purpose of reaching very lofty elevations, the action of the wind upon it should exhibit the highest possible efficiency as the word is defined in the principle enunciated above. All those actions or effects which tend to incline the resultant away from the normal will cause the kite to be correspondingly depressed in angular elevation. Since for meteorological purposes, other things remaining the same, we aim to secure the maximum possible angular elevation for the kite, those effects which tend to depress the kite in angular elevation are of a harmful character and it will be convenient, hereafter, to employ the word harmful in this sense.

It will not be appropriate in the present article to discuss the diagrams of forces for different cases of wind force and direction, nor to develop the best arrangement of bridles, etc. Many experimental difficulties are encountered in seeking exact numerical solutions for ordinary practical cases, and many observations are required. The writer having indicated, in a general way, how the action of the forces affecting the kite may be studied, hopes that experts at work on the problem may test these ideas, pointing out errors and defects that doubtless exist, but especially that they may set about securing the observational and numerical data which are so much needed in order to convert the kite, hitherto almost without exception the toy of boys and men, into the highly efficient and useful piece of scientific apparatus which it seems destined to become.

FORMS AND CONSTRUCTION OF THE WEATHER BUREAU KITES.

The modification of the Hargrave kite, devised by Mr. Potter, and which we have called the diamond-cell kite, was extensively tested in our first experiments. The details of construction of this kite have been minutely given in the MONTHLY WEATHER REVIEW for November, 1895, and their repetition here will not be necessary. The kite is shown in Fig. 40, from which the construction will be understood. Numerous minor variations were made in the main proportions, and in the dimensions of the sticks, etc. The main object in view at that time was to reduce the weight of the kite as far as possible without impairing the strength to such an extent that it would break when severely strained in the wind. This was effected by tapering off the sticks and otherwise shaping them so that the greatest amount of material was concentrated at the points of the greatest strains. This form of kite is exceedingly simple of construction and possesses the advantage of being collapsible for convenience of storage or transportation.

One defect that may be pointed out in the diamond-cell kite consists in the presence of the comparatively sharp angles between the cloth surfaces where they meet at the side edges of the kite. The upper surfaces are greatly sheltered by the lower surfaces near these side edges, and we can readily perceive that eddies, whose harmful effects were pointed out in a preceding paragraph, must be present to a serious extent. The writer devised and tested during December, 1895, two forms of multiplane kites, in which it was sought to avoid the objectionable effects of the sharp angles referred to above and still secure lightness of construction. Fig. 41 shows the first form tried. The result was a failure, so far as flying successfully was concerned. The two very small webs of cloth, *a a*, were the only vertical surfaces introduced, and the trial proved that the kite lacked those steady, stable qualities so generally found in kites of the cellular type. It was concluded that good results could be obtained by connecting the outer ends of the horizontal sustaining surfaces with cloth, so as to form a greater extent of side surfaces adapted to steady the motions of the kite.

The second form of kite carried out this idea. It is shown in Fig. 42. The only kite made of this kind was unsatisfactory because the frame work proved to be too light. Its flying qualities seemed to be as good as those of most of the kites tested at that time. The side planes are so steeply inclined as not to form the sharp angles found in the diamond kite.

Further experiments with these forms were resumed on different and better lines after the studies and experiments relating to the strength of the wire, the manner of splicing, measuring, reeling it, etc., were made.

While this work was in progress during the early part of December, 1895, a great variety of forms of kites were considered by the writer, even though time was not then available to make up and test them. The more important of these forms are shown in Figs. 43 to 46. Bearing in mind the conditions which ought to be satisfied by a good kite (p. 162), a brief mention of the points of advantage in the several designs will be sufficient.

Fig. 43 represents a Malay kite with an upper or superior sustaining surface, *a*. It will also be noticed that the bowed cross-stick, *C D*, is in front of the cloth. The object of this is to eliminate the harmful effects pointed out in connection with Fig. 39. The presence of the superior sustaining surface will cause the center of pressure to fall back of the midrib and thus tend to increase the lateral stability, which may be further improved by use of a bridle arranged according to the principle to which attention was called in connection with Fig. 38. In order to steady the kite a vertical web of cloth, or dorsal fin may be required. Both these modifications are shown in Fig. 44.

Fig. 45 indicates the application of a relatively weak propelling apparatus to the line beneath the kite. Such a device, if not too heavy in proportion to the lift of the kite and the thrust of the propeller, will, as shown, cause an angle to be formed in the string near the kite, so that the portion below the propeller is much more nearly vertical than the portion next the kite. The advantages of this will be more fully brought out when we treat later of the properties of the catenary or the curve formed by the kite wire or string. The motor is supposed to be operated by energy stored within, or by electricity, or possibly the necessary energy may be derived directly from the variations in the wind itself. It is well known that the wind constantly varies in force. Imagine the propelling arrangement to be driven by a steel spring, it is plain that with the aid of suitable mechanical devices every time the force of the wind increased the greater tension on the wire could be made to wind up the spring more or less. Or, the variations in the wind force might be made to flap wings in some useful manner. If the variations in the wind force proved to be inadequate the wire at the reel might be alternately pulled and slackened so as to produce considerable variations of tension. These ideas, it is believed, possesses some novelty and possible merit.

Fig. 46 shows the original idea from which the kite illustrated in Fig. 42 was evolved.

Mr. H. Chadwick Hunter of Washington, D. C., who interested himself in the kite work of the Weather Bureau, and who flew kites for his own amusement and outdoor exercise, introduced a noteworthy modification of the diamond-cell kite. This was in December, 1895. A Malay kite was cut in half lengthwise, and the triangular segments thus formed attached to the sides of a diamond kite, forming the winged kite shown in Fig. 47. Considerable additional sustaining surface is thus gained, with but a slight increase of weight. Several kites of this type were employed in the Weather Bureau work. In some the wing surfaces were made quite large. The results, however, were not so satisfactory. Seemingly, the best proportions are obtained when the greatest width of the triangular wing is not more than one-half the longitudinal dimensions of the kite. A greater width than this will answer well in light winds, but stronger winds are likely to disturb the symmetry of the kite as a result of unequal stretching of the material. Kites of this form took the highest angular elevation of any tested at that time, but experience showed that they could not be fully depended upon to stand as great extremes of wind force as the kite without wings. I think there is much merit in this kite, and it seems probable that by using a heavier and firmer grade of cloth for the wing surfaces, the effects of uneven stretching of the cloth will be less serious or of no consequence. Whether the corresponding increase of weight would detract seriously from the advantage gained by the addition of the wings can only be certainly told by experiments.

It is worth noticing that the amount of sustaining surface in a given kite is a fixed and invariable quantity, notwithstanding that the kite is called upon, or at least we wish it to withstand great extremes of wind force. Up to the present time no attempt appears to have been made to provide arrangements, automatic or otherwise, for increasing or shortening sail. Present practice in kite flying is like sending a yacht to sea with every sail set and without means for either reefing or furling them. The air ship, it is true, does not carry its sailors aboard, but it is not impossible that it may in the future. In the mean time inventive genius needs to provide some means by which the sustaining surfaces of a kite may be easily varied without proportionate variations of weight. One kite may thus be adapted to great extremes of wind force.

In the literature of kites we find the use of flexible surfaces strongly recommended, because, it is stated, the bending of the surfaces under gusts of wind eases off the severity of the strain and is otherwise attended with good effect. We have in this a means of automatically adjusting the expanse of sail to the force of the wind. The idea is good enough, in its way, but when we examine into the degree of flexibility provided and compute the diminution in pressure resulting from the maximum possible flexure, it will be found that the provisions ordinarily made will prove entirely inadequate and that the great advantages claimed are largely imaginary. The force of the wind at 30 miles per hour is fully nine times as great as at 10 miles per hour. The supposition that the flexure of a wing surface of a few degrees can contribute in any important degree to compensate for nine-fold variations in pressure, is plainly untenable. We shall have occasion later to discuss this point to some further extent.

The winged kite, described above, may easily be constructed in such a way that the wings may be removed or furled, and the amount of sustaining surface correspondingly diminished when strong winds prevail. This is perhaps a first step in the direction of providing a variable expanse of sustaining surfaces.

Mr. Hunter also devised and constructed the kite shown in Fig. 48. This was very successfully flown early in February, 1896. Other forms of kites proved to be superior, however, and more desirable in several respects.

It is important to notice that a kite almost precisely similar to the winged cylinder kite of Mr. Hunter was devised by Mr. W. H. Hammon, Forecast Official, in charge of the Weather Bureau office at San Francisco, Cal. Accounts of the first trial of this kite were published in the San Francisco Chronicle of April 2, 1896.

Fig. 49 is a drawing made from a photograph of this kite. Mr. Hammon dispensed with the ordinary bridle as a means of adjusting the string to the kite and adopted a novel bowsprit arrangement. His device is described in his own words as follows:

Instead of attaching the string to the kite by a bellyband, I use a stick, the end of which is attached to the backbone of the kite about two-thirds of the distance back from the front edge of the first cell and then passed diagonally through the cell and out at the bottom of the front edge, where it is also fastened and extends about 16 inches downward in this diagonal direction. The string is then attached to this lower end.

Speaking of securing automatic adjustability to winds of different force, he says this is also gained:

By attaching the bowsprit to the upper side of the cell only and then passing it through a rubber hose attached to the front edge of the lower side of the cell instead of to the cell itself. The string is then fastened to the hose instead of to the bowsprit. The point intended to be gained is that the cell will spread with a high wind, thus narrowing the surface normal to the wind and diminishing the strain upon the string, at the same time the bowsprit will be drawn further back in the hose, thus shortening the distance it extends below the lower edge of the kite, which causes the kite to hang more nearly parallel to the wind and thus diminishes the strains upon the string.

A kite of this form has not thus far been tested at Washington.

Attention has already been called to the tendency of the cloth covering of kites to form waves and to emit a comparatively loud sound caused by the fluttering. The manner in which energy may be wasted in this action has also been shown. The full significance of this action did not force itself upon me, at first, and many experiments were made with kites of various forms, the cloth of which, scarcely without exception, fluttered more or less at all times.

When the actual work of constructing improved forms of kites was resumed after the special investigations upon the best arrangement of kite line, reel, etc., were completed, the writer had become fully awakened to the importance and harmful effects of waviness, eddies, edge pressures, etc. After careful thought in the light of this knowledge, he was fully convinced that the simple rectangular cell of the regular Hargrave kite is a most excellent form of cross section of the cell. The sustaining surfaces are disposed in the position of maximum effectiveness, as are also the vertical side surfaces, whose special function is to steady the motions of the kite and contribute to the lateral stability thereof. The causes which can produce eddies are present in less degree than in many of the forms already described. The plan of construction practiced by Hargrave and followed by Mr. Potter does not, however, prevent fluttering of the cloth. From these considerations, however, I am led to the belief that the simple rectangular cell is already the best form we have as the basis of cellular and multiplane kites.

The problem was, therefore, how to improve this kite. To solve this problem the writer sought (1) to lessen the weight of the kite without loss of strength; (2) to reduce harmful edge resistances; (3) to suppress waviness and fluttering; (4) to lessen and eliminate eddy effects, and, finally, in order to increase the pull of the kite, other things remaining the same, (5) to arch the surfaces of the cloth.

The plan practiced by Hargrave of constructing the frame of the rectangular cells is shown in Fig. 50, so far as it can be made out from the general illustrations published by him in American Engineer, April, 1895. The details of the joints in Fig. 50 are due to Mr. Potter, and while the suggested construction there indicated may be helpful to beginners, the point has no important bearing on the general plan of the frame. The important dimensions of a kite made according to this plan are indicated on the drawing. The sustaining surface of the kite is 24 square feet. The dimensions of the sticks (straight-grained white pine), where important and not shown on the drawing, are as follows:[1] All diagonal struts are ½ inch square, shaved round and notched and cleated on the ends. The struts are firmly lashed together at points of crossing. All longitudinal sticks (six in number) are ¼ by ⅝ inch, edges rounded. The four lateral longitudinal sticks are made narrow between cells. These sticks need not be made continuous. They were not so made by Hargrave. By making them continuous and stringing them with a complete system of diagonal ties made of fine, spring, phosphor-bronze wire, the frame of the kite is better able to withstand twisting and distortion. Made in this way the kite will prove to be an excellent flyer, and with winds of 12 miles per hour and over will be capable of reaching considerable elevations.

Improved construction.—A modified construction of this form of cell is shown in Fig. 51. This, so far as known to the writer, has not been employed or described before. Sufficient details are therefore given to enable others to use it, if desired.

Rectangular frames.—Slender frames, square dovetailed at the corners, as shown in Fig. 52, constitute the basis of the cells. The frames are made remarkably strong and rigid against forces acting in their own plane by means of the diagonal wire ties and the strut through the middle. The sticks for kites of from 24 to 40 square feet of sustaining surface are of ¼-inch white pine, or spruce, ⅝ inch wide, slightly more or less in proportion to the surface. All wire ties are of the best phosphor-bronze spring wire, 0.028 of an inch in diameter. To insert the wires so as to insure accuracy in the form of the frames, strips of wood are nailed to the top of the workbench so as to form a true rectangle, within which the slender frame will snugly fit. The end of a wire is passed through inclined holes at A. A small fragment of sheet tin is placed under the wire to prevent it from cutting its way into the wood when strained. One end of the wire is carried around the joint D and twisted in the manner shown. If not already done, the frame must now be placed within the rectangular form on the workbench. While held in perfect shape therein the remaining end of the wire is passed around the joint at C and secured by twisting while under considerable tension. The strut $A\ B$ is generally only temporary. Any small stick answers the purpose, and it need not be secured within the frame in any way except as it is held by friction. The longitudinal truss on midrib of the completed kite generally takes the place and serves the purpose of the strut $A\ B$. The frame is completed when the wire $E\ B\ F$ is inserted and fastened.

To secure the proper tension on the wires requires a little experience. Too much tension may easily be obtained, although if the knack of twisting both the wires equally is not possessed the joints may slip and the wire become too slack. With the right degree of tension the frames warp more or less out of true when taken singly. This is corrected when the frames are assembled.

In describing the best manner of splicing wire by twisting it was pointed out that both wires must be twisted around a common axis. The wire ties in the frame just described must be twisted in the same way. It takes but a moment to solder the twisted joints, and their strength is very greatly increased. The wire is also soldered to the pieces of tin at A, B. The wires at crossings are sometimes wrapped with

[1] To avoid repetition here, the reader is referred to the MONTHLY WEATHER REVIEW for November, 1895, for minute details concerning the construction and joining of the framework.

finer wire and soldered; often, however, they are simply tied with fine strong waxed twine or thread.

The next member of the frame work is the piece employed to join the frames with each other at the corners. Fig. 53 shows the form of the stick and the tin angle pieces at the ends. The stick, originally $\frac{1}{2}$ inch square, is shaved down tapering and parallel to the diagonal to about $\frac{1}{8}$ inch at the ends. The tin angle pieces are secured to the ends of the stick by lashing with No. 22 gilling thread thoroughly waxed.

The cell.—The manner of connecting the frames with each other is shown in Fig. 54. Two connected frames constitute the cell, minus the covering. This is simply a long band of cambric, generally $\frac{1}{2}$ yard wide. After the strip of cloth has been torn to width and hemmed, the length is ascertained by stretching the edge around one of the frames, marking off, with pencil, where the stitching is to come. The opposite edge of the band is stretched around the frame in a similar manner and marked. The ends of the cloth are laid out smooth and pencil lines drawn across from the marks at the edges. These lines are overlapped and matched exactly. The cloth is then stitched on the mark and the seam finished as suits the taste of the operator. This method gives a cloth covering that fits perfectly. The tightness with which the cloth fits may be varied to suit circumstances. The cloth need not in any case be very tight.

The complete frame of the cell may be put together and the cloth slipped over afterwards. This requires some care to avoid pulling the cloth awry. I prefer to set up two of the frames on edge and connect them at the angles by means of the connectors shown in Fig. 53, three of which are simply laid in place between the frames with the band of cloth loosely on the outside. When the fourth is put in place the cloth comes under tension and all the parts hold together with some security. The corners may then be lashed together, as shown in Fig. 54. The edges of the cloth are secured to the cell by tacking it to the frames at intervals of several inches. I prefer, however, to secure it by sewing through the hem of the cloth and around the sticks of the frames. Stitches between one and two inches apart are sufficient. Fine bookbinders twine is generally employed for this purpose. Fully two square feet of sustaining surface is gained in a kite of thirty-two square feet, by this method of sewing, as it is not necessary to make the cloth overlap the frames.

Longitudinal truss.—Two cells joined by some sort of longitudinal truss make the complete kite. Several methods of trussing the cells together have been tried, but thus far, I think the strongest, most rigid and at the same time sufficiently light truss has not been developed. In the first kite made according to the new construction, the cells were connected at their four corners by a different plan than described above. Four long connecting pieces extending the full length of the kite were employed, and in another case two strong trusses similar to one shown in Fig. 55 were placed, one at either side of the kite. Either of the above plans of connecting the cells forms a very rigid and strong kite frame when reinforced with diagonal ties of wire. The principal objection to the arrangement of trusses just described is the fact that no good place results at which the bridle can be attached. Either an additional piece or supplementary truss must be placed in the central or median plane of the kite to which a simple bridle may be attached, or, in the absence of such a piece, a more complicated bridle must be rigged to draw from the lateral lower edges or corners of the cells. The first plan requires the addition of weight that ought not be necessary. The bridle of the second plan when under tension produces heavy compressive strains upon the frames of the cells, increasing the load these frames already carry as a result of the direct wind pressure upon the cloth. Neither plan is therefore quite satisfactory. The manner of joining the cells, illustrated in Fig. 51, was subsequently adopted and found more satisfactory. The truss itself is shown in Fig. 55.

The first kite made with a truss of this form is shown in Fig. 56. The slender, diagonal side braces a a and b b, Fig. 51, had not, at that time been introduced. Without them the kite lacks rigidity against forces acting at right angles to the plane of the truss. No difficulty on this account ever occurred with the kite shown in Fig. 56, which has seen a great deal of service, but the diagonal side braces are considered an improvement in most cases. Furthermore, in flying these kites in tandem mishaps caused by the main wire getting caught *between* the cells of the kite are prevented when the cells are connected with each other at their lateral edges. Very slender connectors are adequate both to stiffen the frame and to keep the wire from between the cells.

Advantages of construction.—The distinctive feature in the above described construction of the cells lies in the fact that the cloth is bound with wood at all edges. Being thereby made perfectly firm and rigid, it is found the cloth exhibits no tendency whatever to flutter or break up into waves. The kite flies in perfect silence, save a slight whistling of the wind over the wire ties. It is believed there is another important advantage in this construction, namely: a slender vertical strut, at A B, $\frac{1}{4}$ inch thick, is the only obstruction to the free flow of the air through the interior of the cell, except the fine, diagonal tie wires. Referring to the Hargrave construction, shown in Fig. 50, it may seem, at first thought, that the slender diagonal struts employed can have but very little harmful influence. When we remember, however, the effects of eddies and observe that the struts themselves and especially the relatively bulky knobs at the ends, where they thrust against the longitudinal members of the frame inside the cell, as also where they cross, are all fruitful causes of eddies, we are forced to the conviction that their elimination can not fail to prove highly beneficial. In the improved construction described, the minimum obstruction is offered to the easy flow of the air over all the surfaces and through the cells of the kite. In the old construction the edges of the cloth are thin and perhaps form a sharper cutting edge than the $\frac{1}{4}$-inch rounded wooden frames with which the cloth is edged in the improved construction. I am inclined to think, however, that the thin edge of the cloth has only seemingly the advantage here. The contrast and comparison must be drawn between the thin, pliable, possibly loose and fluttering edge of cloth and the smooth, rigid, slightly thicker wooden edge. I am strongly convinced that the actual edge pressure upon the wood with even the bluntly rounded edges I have employed is but a trifle if any greater than upon the thin edges of cloth, as ordinarily found, and which is loosened up considerably in a very few minutes when exposed to the wind, even when originally made very taut.

The superiority of the new construction as brought out by the above analytical considerations is abunnantly sustained by the results of exact observations and measurements. These will be presented in a later section of this article.

The principal objection I entertain to the construction which has been described is the weight[1] of the frame which, thus far, has been found to be some 20 per cent heavier than frames of similar size of the Potter-Hargrave construction. Even though handicapped by this greater weight, the performance of the kite, owing to the advantages already pointed out, surpasses in excellence that of any kite yet tested. On account of weight, however, the kite is not well adapted to work in light winds.

How further improved.—When the best general proportions

[1] The weight of the best and strongest kite thus far made is about 1.9 ounces per square foot of sustaining surface.

of a given kite have been fully brought out as a result of exact and systematic measurements upon the behavior of the kite, it is my purpose to critically analyze the strains upon every member of the kite frame, and proportion the strength of each member to the strain it must bear. The whole structure of the kite is a system of connected trusses, the strains upon the several parts of which may be easily determined by the methods so commonly employed in the construction of bridges and similar framed structures. This method of analysis can not fail to result in an increase of strength and decrease of weight, as all material will be employed to the best advantage.

The longitudinal truss, made to the dimentions indicated on the drawings, has, in some cases, proved too weak. At the present stage of the investigations considerable attention has been given to finding the best proportions for the distances between the cells and between the surfaces of a single cell, also, the proper width of the cloth bands. Much valuable observational data has been obtained, but further information is needed before a definite conclusion can be stated. When the best length for the longitudinal truss of a given kite is definitely known, I think it will be an easy matter to greatly improve the construction of the truss so as to secure adequate strength with the minimum weight. Thus far the sticks of the rectangular frames have been made of the same size throughout, notwithstanding that it is plain not only that some frames on a given kite are under greater strain than others, but that different parts of the same frame receive very different strains.

General remarks on constructions.—It may be added here that the improved construction while in fact very simple to a person with a few tools and gifted with real mechanical dexterity, does not claim to be of such a degree of simplicity that anybody can practice it. The novice with hammer and vise may be puzzled, for example, to neatly form the tin angle pieces shown in Fig. 53. Stringing the wire ties in the frame, just as they should be, may also prove perplexing. These operations take some time and require some skill, but when a cell is completed you have something that can stand the wind. The cloth is not going to work loose and give trouble after the kite has been flying an hour or two in a stiff breeze, neither will the symmetry of the cell be impaired. The original construction of such a kite requires a little more time than other forms, but it retains its efficiency and symmetry a longer time in the end, and, because of this latter quality is less likely to distort and smash itself in a precipitate dash to the earth.

Aside from all these comments on the simplicity of construction, the object of paramount importance ever in the mind of the writer has been to secure the maximum attainable efficiency in the action of a given kite. Other things have been subordinate to this. The old-fashioned slide-valve steam engine, with fixed cut-off for example, is a marvel of simplicity compared with the complex, intricate, quadruple expansion engines of modern type, with balanced valves and automatic cut-off gear. What is the excuse for this complication?—efficiency. The improved engine will do twice the work, it may be, per pound of coal and barrel of water consumed. Just so with kites. One or two efficient kites, a moderate length of wire under an easy and safe-working tension, are all that are required to reach great elevations in fair winds. With kites of less efficiency to reach the same elevation, more kites, more wire, and far greater strains are necessary, increasing greatly both the danger of breaking the wire and the labor of winding it in. The incentive to fly kites to great elevations and thus excell all previous records is naturally very great. To do so on the principle that any kite is good enough so long as the result is attained, may be justifiable in the minds of some, but is hardly scientific. The writer believes that when kites of the maximum attainable efficiency are produced, and of which the strength and weight of the several members are duly and intelligently proportioned to the strains they must bear, just as is done in great bridges, only with far greater nicety, because with kites the factor of safety must everywhere be much smaller than with bridges—when these things are done, flights to astonishing elevations will follow easily of themselves and fewer reports will be read of kites breaking away with great loss of labor, wire, etc.

[To be continued in June REVIEW.]

NOTES BY THE EDITOR.

LONG-RANGE FORECASTS.

On the morning weather map of June 13, as published by the Weather Bureau at Portland, Oreg., Mr. B. S. Pague, the local forecast official, calls attention to the fact that this map shows the first appearance in 1896 of the so-called type of summer weather conditions. Mr. Pague says:

In 1895 this summer type appeared on April 20, and the first winter type following that appeared on November 12. Winter weather, namely, rain conditions, have continued from November 12, 1895, to June 12, 1896. There are two well-defined types of weather on the Pacific Coast, and these have some fourteen modifications. The primary types are, first, the low area moving southward from Alaska along the coast line to the fiftieth degree of north latitude, sometimes lower, then passing eastward; at the same time the high pressure is off the California coast, and it finally moves eastward about the fortieth degree of north latitude. These conditions are peculiar to the winter season and give rain. The second type is represented by the low areas passing eastward about the latitude of Sitka, Alaska, and then moving southeastward on the eastern slope of the Rocky Mountains toward the Great Lakes, the high pressures moving from and along the California coast northward along the coast line to the fiftieth degree of north latitude, thence eastward. These conditions give fair and warmer weather.

The latter type is present for the first time this morning, for this year, and experience has shown that after the first appearance of the summer condition the weather is more likely to be fair than rainy. It is not to be understood that absolute dryness is now anticipated, but rather that sunshine will predominate and the showers will be few.

The high pressure will move eastward over British Columbia and give fair weather and warmer on Sunday; Monday will be fair, and Tuesday promises to be fair and cooler, possibly some sprinkles of rain over western Washington and northwestern Oregon; Wednesday and Thursday should then be fair and warmer. Summer weather types produce weather such as is above outlined.

FROSTS IN CALIFORNIA.

Under date of May 5 Prof. E. W. Hilgard, President of the University of California and Director of the Agricultural Experiment Station at Berkeley, Cal., writes as follows:

The weather conditions in this State have been this year so extraordinary that meteorological observations and forecasts are more than ever called for, and are popularly demanded. Our experience with two of our stations this year has been a sore one, and will most seriously retard the settlement and modify agricultural practice in the districts concerned. At one station we find it necessary to completely remodel the varieties in our experimental orchard, about 50 per cent having proved useless for any practical purpose on account of their sensitiveness to even light frost, and the low temperatures of the summer nights; this at an elevation of only 1,400 feet, and in a locality where wholly unexpected. We are now actually carrying Russian apples and other hardy fruits as far south as the latitude of San Luis Obispo, as the only reasonable hope of the fruit industry in that region. In the great valley of California, too, the havoc wrought by the frost has been exceedingly heavy, and localized in the most puzzling man-

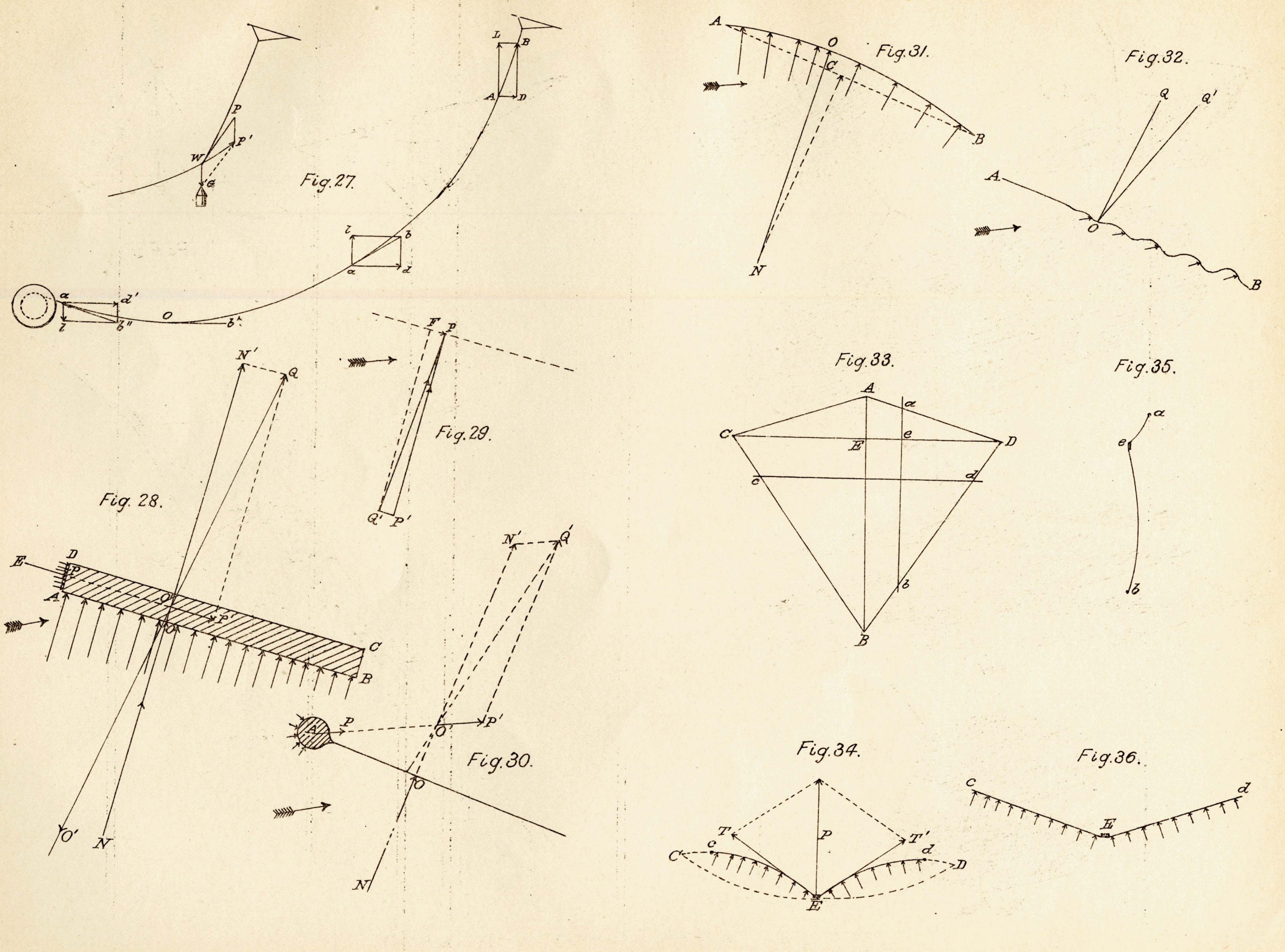


Fig. 27.

Fig. 28.

Fig. 29.

Fig. 30.

Fig. 31.

Fig. 32.

Fig. 33.

Fig. 34.

Fig. 35.

Fig. 36.

Chart X. Kite Experiments at the Weather Bureau.

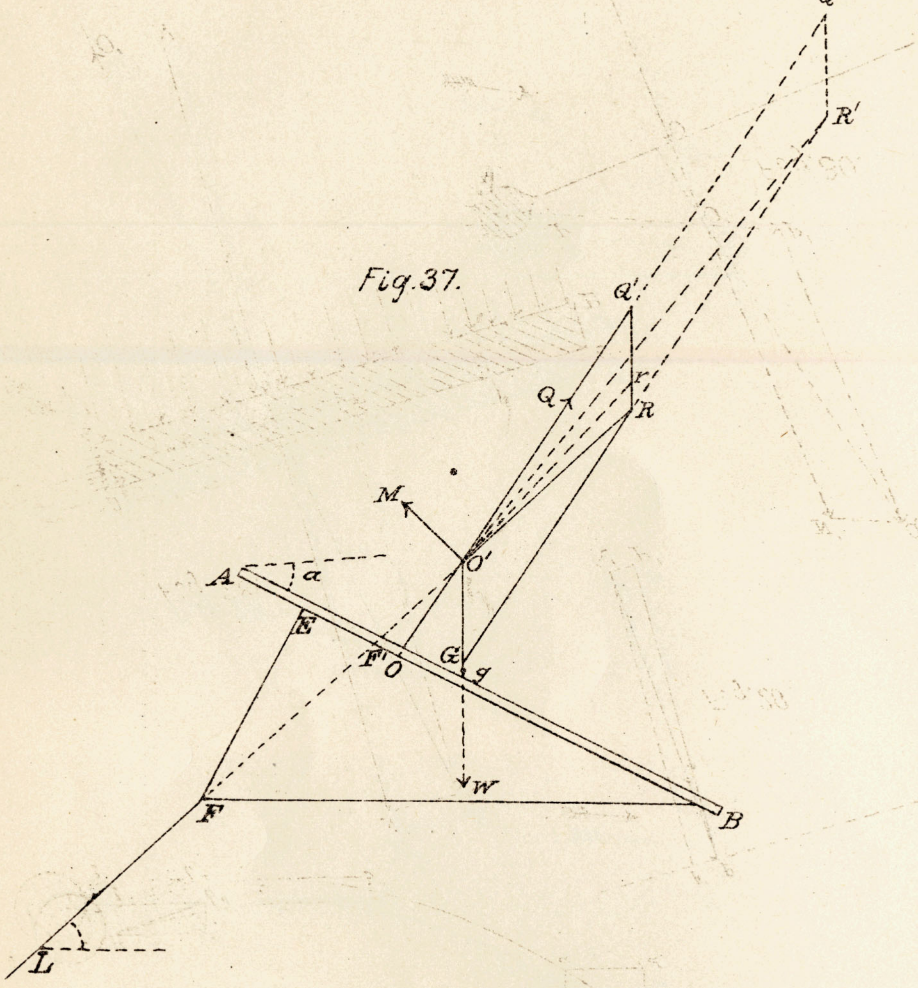


Fig. 37.

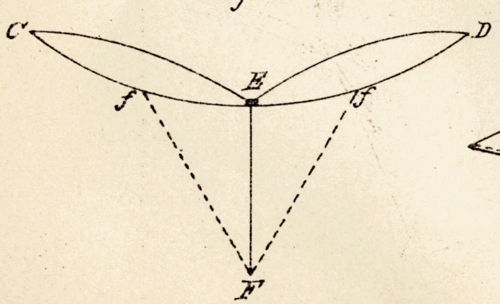


Fig. 38.

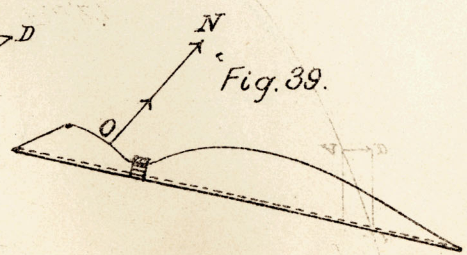


Fig. 39.

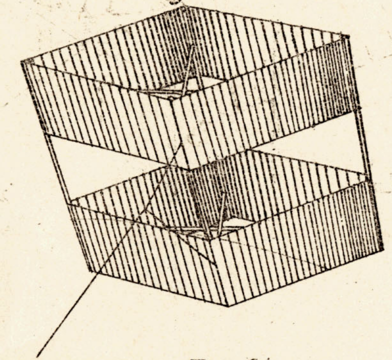


Fig. 40.

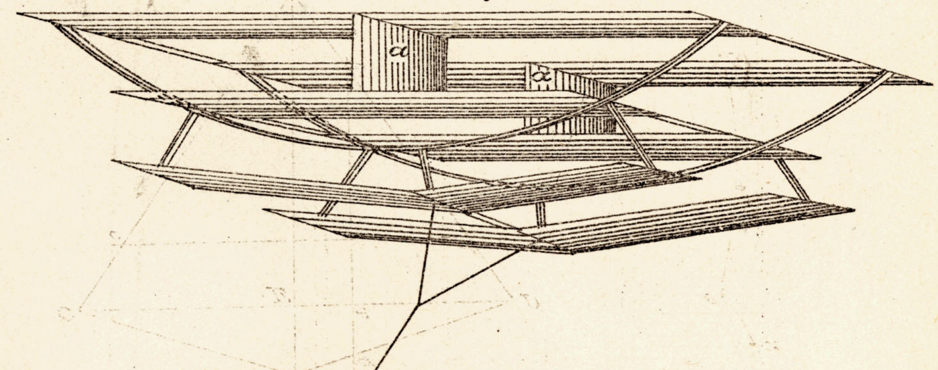


Fig. 41.

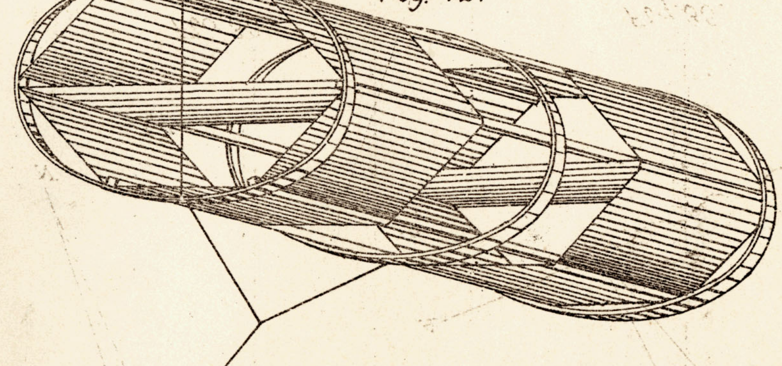


Fig. 42.

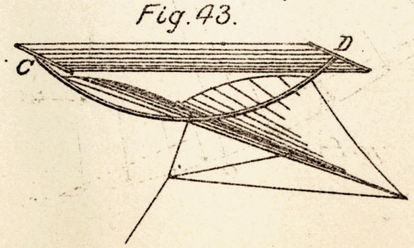


Fig. 43.

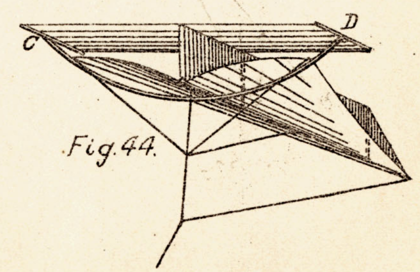


Fig. 44.

Chart XI. Kite Experiments at the Weather Bureau.

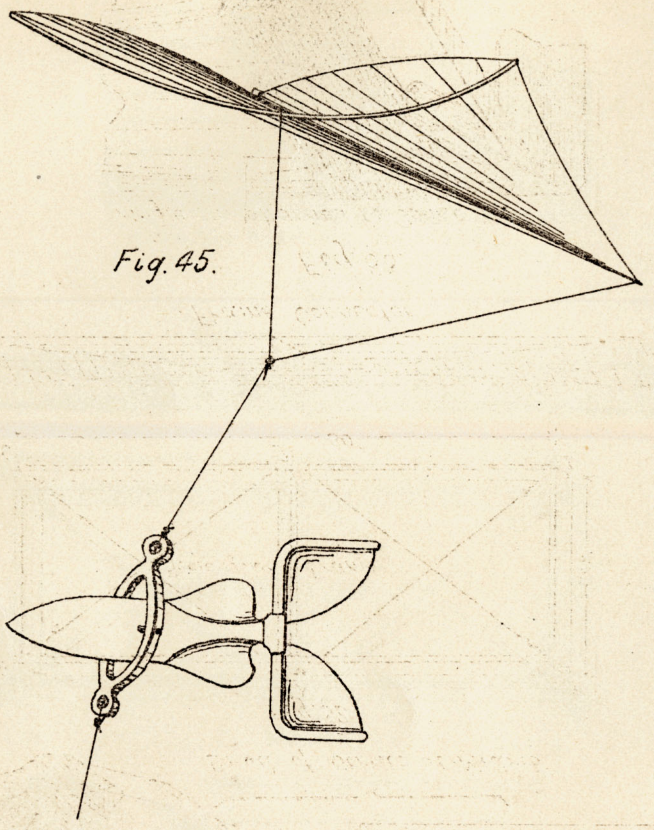


Fig. 45.

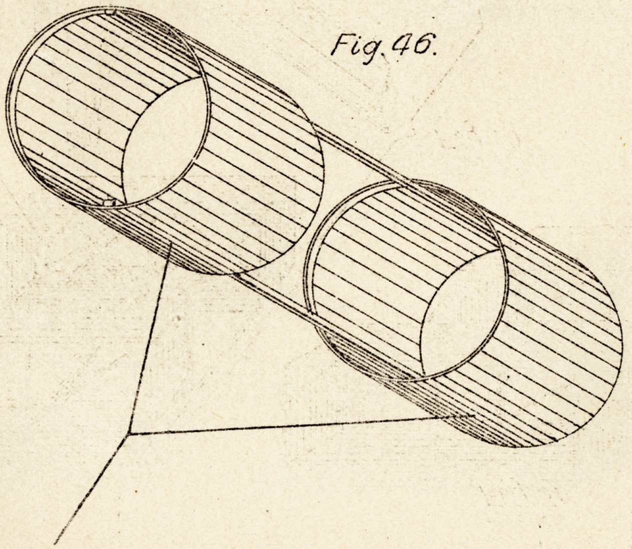


Fig. 46.

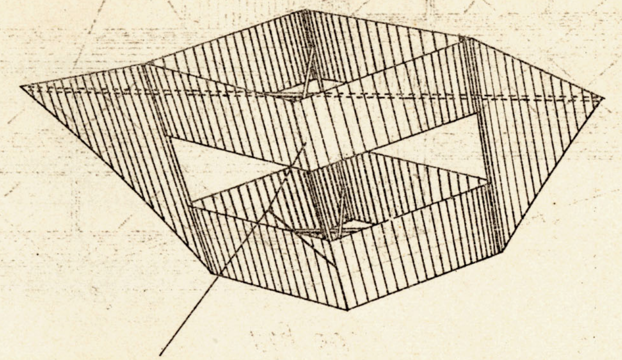


Fig. 47.

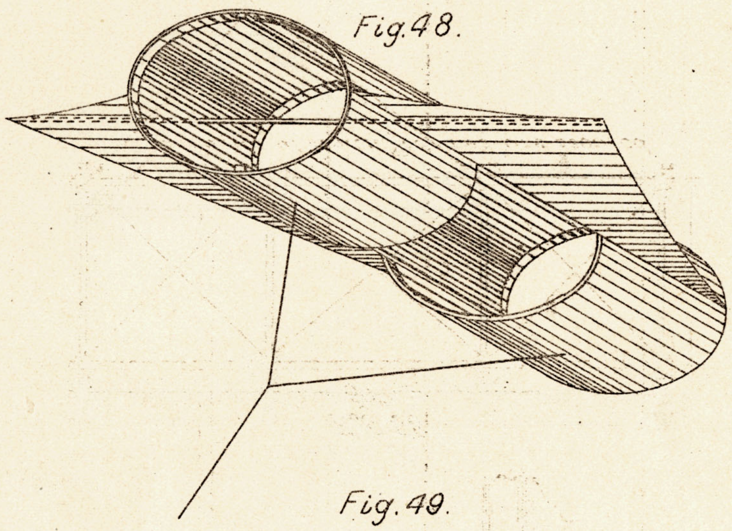


Fig. 48.

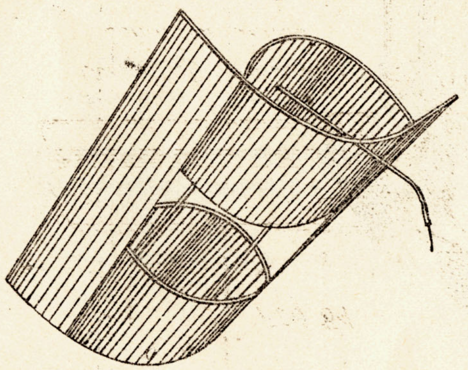


Fig. 49.

Fig. 51.

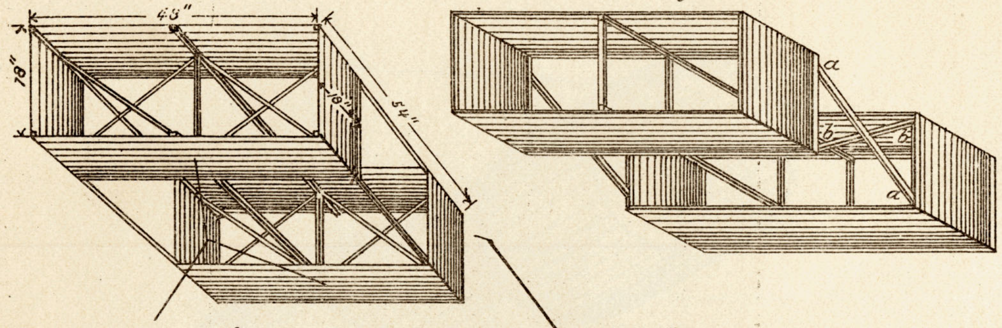
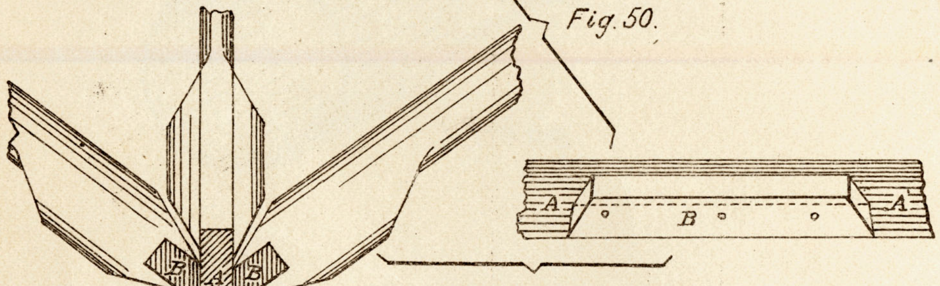
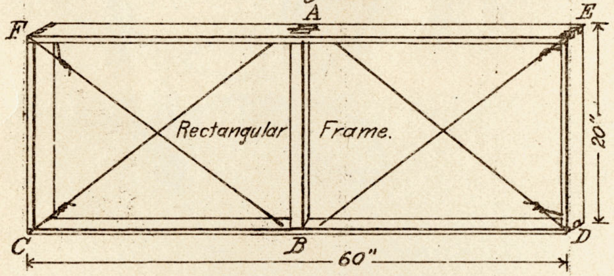


Fig. 50.



Detail of Struts at Midrib.

Fig. 52.



Frame Connector.

Fig. 53.

Angle tin attached to Connector.

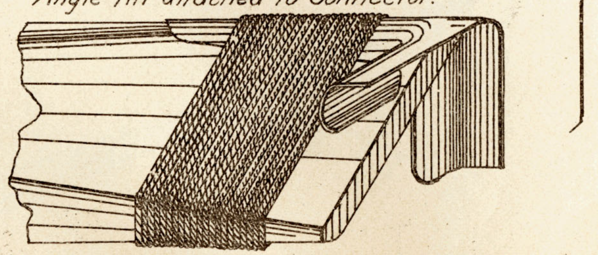
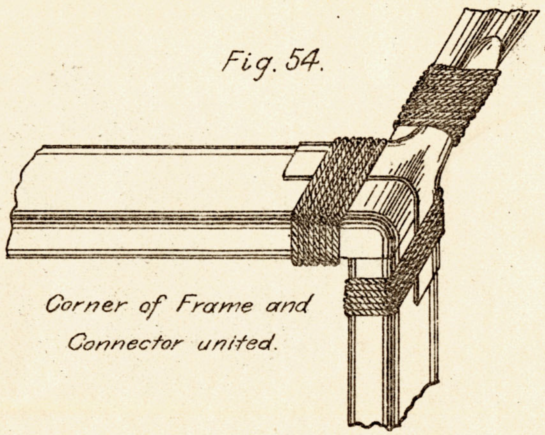
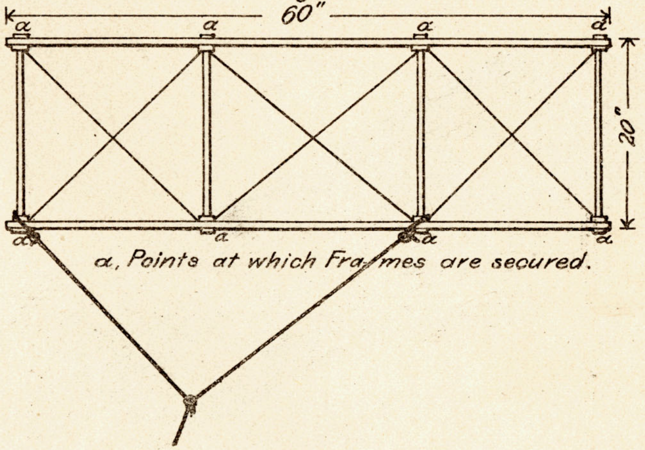


Fig. 54.



Corner of Frame and Connector united.

Fig. 55.



a, Points at which Frames are secured.

Fig. 56.